UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PROGRESS REPORT I

BOUNDARY SHEAR DISTRIBUTION AROUND A CURVE IN A LABORATORY CANAL

Report No. Hyd-526

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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ABSTRACT

Boundary shear distribution determined from hydraulic measurements in a rigid boundary trapezoidal laboratory canal showed that the highest boundary shear occurred on the inside bank at the upstream end and on the outside bank at the downstream end of the curve. Knowledge of how boundary shear varies around a curve and the location of its high and low areas will be helpful in understanding how to reshape a canal-bend cross section to provide maximum stability and in reducing maintenance costs on earth canals. The 50-ft-long by 6-ft-top-width test canal had a 16-ft-radius curve that turned a 15-deg angle with the channel centerline. Instrumentation included a Preston tube for boundary shear measurements, a Prandtl tube for velocity measurements, a point gage for water surface profiles, and a differential pressure transducer connected to a direct-writing electrical recorder for pressure measurements. Data were taken at 10 stations located upstream from, in, and downstream from the curve for 1 flow condition--discharge 2.85 cfs and depth 0.75 ft. Test results are given in graphs, drawings, and photographs showing boundary shear distribution throughout the tested reach, and velocity contours and transverse water surface profiles at 10 stations. In addition to the physical data, the study showed conclusively that boundary shear can be measured with a Preston tube and that shear distribution can be determined in a laboratory facility.

DESCRIPTORS--*trapezoidal channels/ rigid boundaries/ canals/ subcritical flow/ steady flow/ *boundary shear/ water surface profiles/ velocity meters/ hydraulic models/ curves/ model tests/ measuring instruments/ open channel flow/ velocity distribution/ pressure measuring equip/ recording systems/ hydraulics/ graphical analysis/ sedimentation/ irrigation O&M/ unlined canals/ erosion/ bends/ horizontal curves/ tractive forces/ laboratory tests

IDENTIFIERS--shear distribution/ pressure transducers/ point gages/ canal curves/ Preston tube/ Prandtl tube/ test reaches/

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No. Hyd-526
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PROGRESS REPORT I
BOUNDARY SHEAR DISTRIBUTION AROUND A CURVE IN A LABORATORY CANAL

SUMMARY

A study was made in the Hydraulics Branch laboratory to determine the boundary shear distribution around a curve in a trapezoidal laboratory canal. The canal curve had a central angle of 15° with a 16-foot radius to the channel centerline. The canal cross-section dimensions were 2-foot bottom width, 1 foot vertical to 1-1/2-foot horizontal side slopes, and 1.12-foot depth. Water surface, velocity, and boundary shear data were taken at 10 measuring stations for 1 flow condition with a discharge of 2.85 cubic feet per second and 0.75-foot depth. Results are presented graphically: Figure 7 shows the transverse water surfaces at the 10 measuring stations, Figures 8 and 9 contain velocity contours at the same stations and show the velocity distribution in the canal curve. To establish these velocity contours, as many as 153 to 213 velocity measurements were taken at each of the 10 stations. Figures 10 and 11 show the boundary shear distribution in the canal curve. Areas of the curve where high boundary shear occurred were on the inside bank at the upstream end and on the outside bank at the downstream end.

In addition to the physical data referred to above, the study showed conclusively that boundary shear can be measured with the Preston tube and that shear distribution can be determined in a laboratory facility.

INTRODUCTION

The Bureau of Reclamation has many miles of canals constructed in various types of materials. Canals follow fairly closely the contours of the topography and consequently require many curves. When water flows through a curve in a canal, there are secondary currents imposed on the main stream. Also, the velocity distribution of the main stream and the boundary shear distribution on the canal perimeter are altered, due to the effect of the curve upon the waterflow. Secondary currents and boundary shear (tractive force) cause erosion and sediment deposition to take place in the vicinity of the curve. Generally, erosion occurs on the outside of the curve; deposition on the inside of the curve and in its downstream portion. After continued operation, the cross section of an earth canal may become changed, thus creating new flow conditions which are usually more severe in regard to the erosion and deposition forces acting on the canal banks. Replacement of earth materials in the vicinity of a curve is a problem in field maintenance of canals. In many cases, the cross-sectional shape at the canal curve has to be restored to the original trapezoidal shape. In some cases, the canal cross-section has been modified to provide a more stable section. Through experience, one irrigation district has established a definite cross-section shape with the bottom of the canal superelevated, the outside bank made flatter, and the inside bank made steeper than the original slope.

Knowledge of how boundary shear varies around a curve and the location of high and low boundary shear areas would be helpful in understanding how to reshape a canal-bend cross section to provide maximum stability. To obtain information on boundary shear distribution in canal curves, a study was conducted in the Hydraulics Branch laboratory using a trapezoidal canal with a fixed boundary constructed of sheet metal. An erodible canal would seem to be more representative of field conditions, but it is very difficult to make boundary shear measurements on erodible surfaces. Therefore a rigid boundary model was used to obtain the boundary shear distribution data. A full understanding of the boundary shear problem could lead to reduced maintenance costs on earth canals.

THE INVESTIGATION

Laboratory Canal

A trapezoidal canal specially constructed in the laboratory for boundary shear measurements was used in this study. The testing facility included a small inlet box to feed water to the laboratory canal, a 30-foot straight reach leading to the curve, the curved section, and an 18-foot straight reach leaving the curve, Figure 1. The curve had a 16-foot radius measured to the canal centerline, and turned a central angle of 15°. The trapezoidal canal cross-section dimensions were 2-foot bottom width, 1 vertical to 1-1/2 horizontal side slopes, and 1.12-foot depth, Figure 1. The canal had no slope; the bottom of the canal was constructed horizontally. Straight portions of the canal were constructed of wood and covered with galvanized sheet metal. All metal joints were soldered. Excess solder at the joints was removed to make the canal surface smooth. The curve was constructed of metal lath covered with mortar and troweled to a very smooth finish. To give a uniform texture throughout the length of the canal, the entire surface was painted with a marine paint. Tailwater elevation was controlled by placing slats vertically across the canal exit until the desired water surface elevation was obtained. Water entering the canal was supplied through a permanent high-head pump, and measured with the 8-inch Venturi meter located in the northeast bank.

To improve flow conditions in the canal and increase the capacity, the inlet box was remodeled after initial tests were made. Metal lath was installed in the box to break up the flow from the inlet pipe and dampen the turbulent action of the water in the inlet box. Also, a transition leading into the canal was installed. Thus, the effect of disturbances originating in the inlet box and extending into the canal were decreased. The canal capacity (maximum discharge) was increased from 3 to 5 cubic feet per second, and flow conditions for the smaller discharges were greatly improved.

Instrumentation

Three types of measurements were taken: boundary shear, point velocities, and point gage readings of the water surface. These three measurements were taken at the 10 stations shown in Figure 1. At each station, an aluminum U-channel was positioned at right angles to the canal centerline and placed horizontally across the canal. Distances right and left in tenths of feet from the canal centerline were marked on each U-channel. The clamp holding the Prandtl tube or Preston tube was fitted so that it could be moved along the U-channels to position the instruments for measurements.

U-channels at the 10 measuring stations were checked for levelness in the following manner. The canal exit was sealed and the channel ponded with water; this provided a smooth horizontal water surface. With the point gage being moved in intervals to the marks on each U-channel, and being mounted successively upon each of the U-channels, measurements were made to the horizontal water surface. These data were plotted for each station to show any unevenness of the U-channels. Corrections were established and applied to the transverse water surface profile measurements taken later.

Point velocities were measured with a standard 3/16-inch Prandtl tube (outside tube diameter). The Prandtl tube is a form of Pitot-static tube which has been designed so that flow disturbances produced at the nose and leg of the instrument are equal, making the corrective coefficient of the instrument unity, Figure 2.

Boundary shear along the laboratory canal was measured with a Preston tube. The instrument functions similarly to a Pitot-static tube in that it measures dynamic pressure. Figure 2 contains a photograph and Figure 3 is a drawing of the Preston tube used in this study. The Preston tube was convenient to use because it was easy to move from one location of the canal to another and it was possible to measure the boundary shear with one instrument placement. When making a boundary shear measurement the larger lower tube, which is the total pressure tube of the instrument, is placed directly against the canal surface and the difference in pressure (dynamic pressure) between the total pressure tube and the static pressure tube is measured.

From the measured dynamic pressure $(P_t - P_s)$ the boundary shear can be computed using the equation developed by Preston, 1/

$$\log\left(\frac{\tau_o \; d^2}{4\,\rho\,\nu^2}\right) = -1.396 + 7/8 \log\left[\left(\frac{P_t - P_s}{4\,\rho\,\nu^2}\right)d^2\right]$$

The equation is valid within the range,

$$4.5 < \log\left[\left(\frac{P_t - P_s}{4\,\rho\,\nu^2}\right)d^2\right] < 6.5$$

where,

P_t Total pressure, lb/ft^2
P_s Static pressure, lb/ft^2
d Outside diameter of Preston tube, ft
ν Kinematic viscosity of fluid, ft^2/sec
ρ Mass density of fluid, $slug/ft^3$
τ_o Shear stress at boundary surface, lb/ft^2

The original Preston tube had a ratio of inside diameter to outside diameter of 0.6. The tube used in this study had the same ratio and also satisfies the requirement, established in Preston's original study, that

$$4.5 < \log\left[\left(\frac{P_t - P_s}{4\,\rho\,\nu^2}\right)d^2\right] < 6.5,$$

for boundary shear values ranging from $0.0004\ lb/ft^2$ to $0.023\ lb/ft^2$. Boundary shear values measured in this study were in the middle range of the above limits.

1/ Refers to Bibliography at end of report.

The equipment used for making pressure measurements was a differential pressure transducer (variable reluctance with a rated range of 0.5 pounds per square inch) electrically wired to a direct-writing recorder. The pressure measured was the dynamic pressure or the difference between the static and total pressures obtained from the Preston or Prandtl tubes. Clear plastic hydraulic tubing connected the instrument (Preston or Prandtl tube, depending on which tube was being used at the time) to the transducer and transferred the pressures from the instrument to the transducer. Figure 4 is a schematic diagram of the pressure measuring system and Figure 5 is a photograph of the pressure transducer and direct-writing recorder.

Test Data

Data were taken for one laboratory canal flow condition; depth 0.75 feet, and discharge 2.85 cubic feet per second. The water depth was established at the centerline of Station 10, Figure 1. Station 10 was selected as a control station for the depth because it was in the straight reach downstream from the curve. An upstream control station might have been affected by the resistance of the curve. Since it is planned to make further studies with curves of other central angles, a control station below the curve was chosen as the best standard for establishing the depth.

Water surface measurements were taken with a point gage at each of the 10 stations. Corrections for the unevenness of the individual U-channels were made as previously described and these data were then plotted to obtain the transverse water surface profiles shown in Figure 7.

Results of the velocity measurements taken with the 3/16-inch Prandtl tube are shown in Figures 8 and 9. The velocity contours for the 10 stations were determined in the following way. At a given cross section, a number of positions both right and left of the canal centerline were selected for velocity measurement. At each position a number of point velocity measurements were made in a vertical line starting near the boundary and proceeding upward to near the water surface. For each vertical traverse, a plot of the velocity against distance from the boundary was made and a curve defining the velocity profile was drawn. From the velocity profile, distances from the boundary were determined for velocities of 1.3, 1.2, 1.1, and 1.0 feet per second. These data were then plotted on the cross section along with points taken from other vertical traverses. Velocity contours were drawn through the selected points.

Using the Preston tube, two sets of boundary shear measurements were taken for the same canal flow condition. Measurements for the first set were taken at the 10 stations shown on Figure 1. For the second set, measurements were taken at the same 10 stations and also at stations upstream from the curve. Figures 10 and 11 show contours of equal boundary shear and give the shear distribution in the canal. The shear contours were obtained in the following manner; (1) at all measuring stations shear measurements were taken along the wetted perimeter of the canal, (2) the shear values obtained were plotted on a plan view of the canal (a dot showing the location of the shear measurement was labeled with the corresponding shear value), and (3) contour lines of equal shear were drawn, interpolating by inspection between the plotted points.

DISCUSSION OF DATA

Water Surface Profiles

The water surfaces (measured transversely across the canal at the 10 stations) are shown in Figure 7. The elevation for the water surface was referenced to a datum of 0.75 foot which was the depth of water at the canal centerline at Station 10. Water surface elevations were highest on the outside of the curve and lowest on the inside. The maximum elevation difference was 0.014 foot at Station 6.

Velocity Measurements

Numerous point velocity measurements were made to establish the velocity contours shown in Figures 8 and 9. For example, 153 point velocity measurements were taken for Station 1 and 213 point velocity measurements for Station 10. The trend of high velocity shift through the curve may be observed by following the general location of the 1.3-foot-per-second velocity contour through Stations 1 to 10. At Station 1, it is slightly to the outside of the canal centerline; from Stations 1 to 6, it moves to the inside bank; from Stations 7 to 10 (downstream from the curve) it moves to the outside bank.

Boundary Shear Measurements

In Figure 10, it is apparent that the highest boundary shear is at Station 4 on the inside bank of the curve. Also, the path of high boundary shear throughout the curve may be followed. The area of high boundary shear is on the bottom of the canal from Stations 1 to 2, from Stations 3 to 5 the area of high shear is on the inside bank, from Stations 6 to 7 the area of high shear extends from the canal bottom near the inside bank to the middle of the bottom and then downstream along the bottom of the canal. From Stations 7 to 8 the area of high shear is on the outside bank, and between Stations 9 and 10 the area of high shear is on the bottom of the canal. The area of high boundary shear through the curve tends to follow the location of the high velocity filaments passing through the curve.

A second set of shear measurements was taken to determine whether the shear measuring system and data were replicative and whether the boundary shear distribution shown in Figure 10 could be repeated. As can be seen from a comparison of Figures 10 and 11, the results were very similar. In the second determination there was a general trend toward slightly higher shear values, Figure 11, but the same relative pattern showing distribution of high to low boundary shear values was duplicated. The range of shear values measured was from 0.0044 to 0.0073 pounds-foot^2 as determined from differential head measurements with the Preston tube of 0.009 to 0.016 foot of water. Considering the mechanical difficulties in the methods used to make and interpret differential head measurements, it can be concluded that the boundary shear measuring system is consistent. This is proved by the good agreement of Figures 10 and 11.

Looking at Station 1 in both Figures 10 and 11, an unsymmetrical boundary shear pattern about the canal centerline may be observed. To determine whether this unsymmetrical shear pattern was caused by the curve or by the inlet conditions, shear measurements were taken upstream from Station 1. The results are shown in Figure 11. The shear pattern is unsymmetrical near the canal inlet because the water supply pipe was located slightly to the left of the canal centerline. During laboratory canal construction, the small displacement of the inlet pipe with respect to the canal centerline was not considered an important factor in terms of test results. However, after the results showed an unsymmetrical shear pattern, additional velocity measurements were made. For velocity measurements at a station approximately 8 feet from the inlet box, the velocities were slightly higher on the left side of the canal (1.3-feet-per-second left side, 1.2-feet-per-second right side). The investigation showed that to improve the velocity distribution at the canal entrance, a larger inlet box with a baffle between the water supply pipe and canal would be necessary, and a transition from the inlet box to the trapezoidal canal would be helpful. Before continuing tests are made, these improvements will be added and check measurements made to establish the existence of a uniform approach flow.

Studies of boundary shear distribution in curved trapezoidal channels have been made at the Massachusetts Institute of Technology. 2/3/4/ The MIT channel had the following cross-section dimensions: bottom width 24 inches, 1-foot vertical to 2-foot horizontal side slopes and height of side walls 8 inches. The curve had a 5-foot radius, measured to the channel centerline, and turned a central angle of 60°. Most tests conducted were for a flow having a Froude number of 0.5, where the characteristic length (d_m) in the Froude number ($F = V/\sqrt{gd_m}$) is the mean depth (cross section area divided by the surface width). In the Bureau of Reclamation tests the curve had a 16-foot radius to the canal centerline and turned a 15° central angle.

Canal cross-section dimensions were 2-foot bottom width, 1.12-foot depth, 1-foot vertical to 1-1/2-foot horizontal side slopes, and the Froude number was 0.3. Only a rough general comparison can therefore be made between the results of the two studies. In both studies, the high boundary shear occurred on the inside of the curve and crossed to the outside bank downstream from the curve. Also, velocity distributions were similar in that the higher velocities were near the inside bank of the curve, crossing to the outside bank downstream from the curve. Tests on a more pronounced curve will be necessary before a direct comparison of results with the MIT work can be attempted.

Future Tests

Bends having greater degrees of curvature and larger central angles should be investigated to extend the range of boundary shear data. The ultimate purpose of future studies should be to determine whether bends having a relatively steep inside bank and a relatively flat outside bank might have better boundary shear distribution properties in relation to erosion forces than regular trapezoidal-in-cross-section curves.

APPENDIX

Calibration of the Pressure Measuring System

As indicated in Figure 4, the pressure cell or transducer could be loaded with a known differential pressure to calibrate the pressure measuring system. The purpose of the calibration was:

1. To establish a datum line of zero pressure on the recorder paper.

2. To establish a specific recorder paper distance to represent a specific pressure.

The five-step procedure for calibrating the pressure measuring system is as follows:

Step 1. Turn valves of the instrument (Prandtl or Preston tube) network off and the valves of the calibration network on, thus loading the transducer through the two reservoirs. One reservoir is connected to one side of the transducer and the other reservoir is connected to the opposite side.

Step 2. Open the valve between the two reservoirs and allow both reservoir water surfaces to reach the same elevation. The transducer then has equal pressure on both sides, and gives a zero pressure differential on the recorder paper.

Step 3. Close the valve between the two reservoirs and raise Reservoir "B" (attached to a point gage mechanism) 0.01 foot.

Step 4. Adjust the recorder pen for a deflection of 10 mm from the established zero line. The scale used on the recorder paper was therefore 1 mm equals 0.001 foot of water. Note that the actual pressure measurement is in feet of water.

Step 5. Turn the calibration valves off, the instrument valves on; the system is then ready for operation.

Operation of the Pressure Measuring System

The power switch of the recorder was turned on and the recorder allowed to "warm up" for at least 30 minutes. This "warm up" period made the recorder more stable and reduced the tendency for the needle to drift from zero. The recorder was then balanced, and the measuring system calibrated as described. Valves of the calibration network were turned off and the valves connecting to the instrument were turned on. Previously, the instrument (Preston or Prandtl tube, whichever was being used) had been placed in a large jar of water and the air thoroughly bled from the clear plastic tubing and the instrument. Since the instrument was in still water (no impact pressure) the pressure tranducer was in effect equally loaded on both sides which gave a zero differential pressure condition. A check against the established zero pressure line on the recorder again was made. To place the instrument into the canal, the jar (with the instrument and water still in it) was picked up and submerged in the canal. The instrument was then removed from the jar and attached to the aluminum U-channel of the measuring station, being careful to always keep the instrument mouth submerged. After taking measurements for 2 to 3 hours, the instrument was removed from the canal, again using the jar and keeping the mouth of the instrument submerged in water. A check on the position of the recorder needle with respect to the previously established zero line again was made to be sure that no drift had occurred. A calibration recheck was also made as described. After the system had been operated for some time and a number of these checks had been made, it was found that the calibration of the recorder was very stable, but that generally there was a small amount of drift of the needle on the graph from zero (0.5 mm or less).

If the hydraulic connecting tubes from the instrument were disturbed, the recorder needle moved violently and hit the stop that prevents it from going off the paper. On one occasion, it was noted that the zero line on the recorder shifted 3 mm (0.003 foot of water) when the tubes had been stepped on. From further investigations it was determined that the zero line on the recorder could generally be moved from 0.5 mm to 2 mm by shaking the plastic tubes. Thereafter, when measurements were taken, the area near the pressure measuring equipment was blocked off to prevent inadvertent disturbances to the hydraulic tubing. Experience showed a need for checking the zero pressure line of the recorder more frequently (every 1 to 2 hours) and making calibration checks less frequently.

Differential Pressure Measurements

The measurement of differential pressure was shown on the paper of the direct-writing recorder as a distance from the established zero pressure line, 1 mm equals 0.001 foot of water. Figure 6 is a portion of the recorder paper and shows the trace of the recorder needle when a differential head measurement was taken. Variations in this recorded line are caused by velocity and/or pressure fluctuations in the flowing water. The magnitude of these variations was damped by partially closing the valves to the tubing (impact and static pressure tubes leading from the Preston or Prandtl tube to the pressure transducer). To obtain a differential head value from the chart, an average displacement of the recorder line from the zero line was determined. A rectangle of clear plastic with a thin black line drawn on it was placed over the recorder paper, with the black line parallel to the trace line. By eye, the fluctuations on each side of the black line were balanced, and the distance between the black line and the zero line was taken as the average differential head. The accuracy of this method was surprisingly good; the probable errors were small enough to be considered negligable.

Prandtl Tube Coefficient

The equation $V = C\sqrt{2g\Delta h}$ is a general equation used to compute velocities from data measured with a Pitot-static tube; V = velocity, C = correction coefficient, g = gravitational acceleration, and Δh = differential head between the static and total pressure of the Pitot tube. The correction coefficient C is usually needed because the correct static pressure is not indicated by the Pitot-static tube. The distance upstream from the instrument stem, or downstream from the instrument mouth, that the static pressure holes are located has an effect upon the static pressure indication. The Prandtl tube, however, is a Pitot-static tube that has been designed so that water flowing past the instrument does not affect the static pressure measurement and the correction coefficient, C, is 1.0.

Accuracy of the static pressure measuring portion of the 3/16-inch Prandtl tube was checked to determine whether the coefficient was 1.0. The static pressure check was done in the following way. The Prandtl tube was placed in a channel where the average velocity of the waterflow could be changed from zero to approximately 4 feet per second. The instrument was placed approximately 0.5 foot above the bottom of the channel with the static pressure holes of the instrument directly above a piezometer tap in the channel bottom. Water was then ponded in the channel. One side of the pressure cell was connected to the piezometer tap and the other side to the static pressure tube from the instrument. Both sides of the pressure cell thus had the same load applied (same height of the water above the pressure cell.) The line traced on the recorder then represented a zero differential pressure. Flow in the channel was started and the velocity was increased from zero to approximately 4 feet per second. If water flowing past the instrument caused a pressure change in the vicinity of the static pressure holes of the instrument, the recorder would show a pressure difference between the static pressure measured by the piezometer tap in the channel bottom and the static pressure measured by the instrument. In practice, small deflections of the recorder needle to both sides of the zero line were found, but the average of the deflections was still on the zero line. Since no measurable difference was found between the two static pressure measurements, it was concluded that the correction coefficient for the 3/16-inch Prandtl tube was 1.0. A similar test was performed for the Preston tube with similar results.

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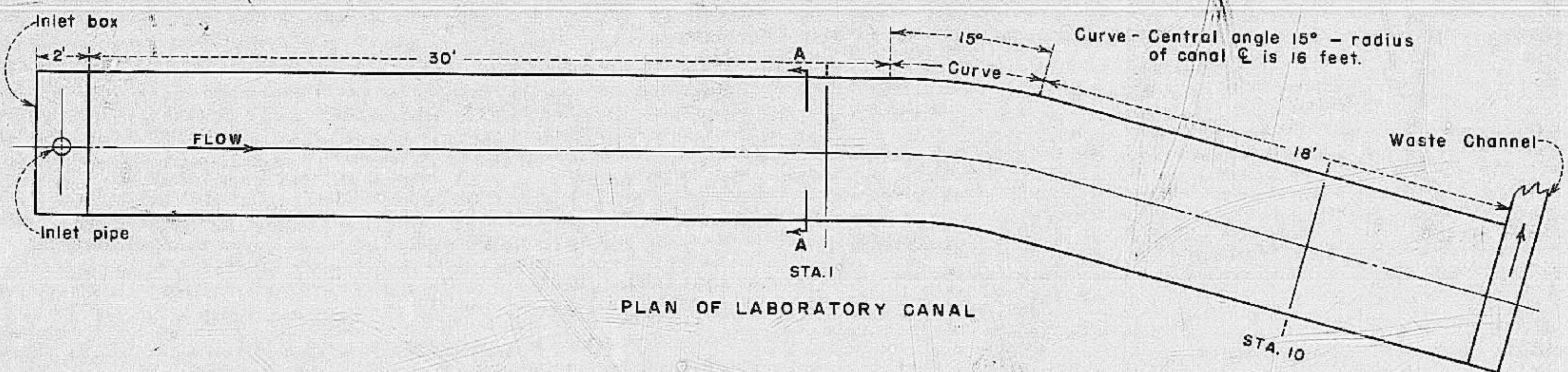
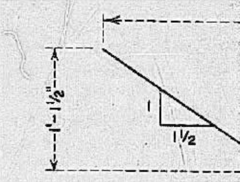
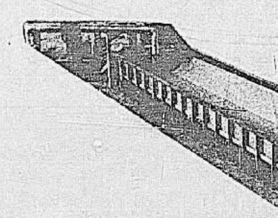
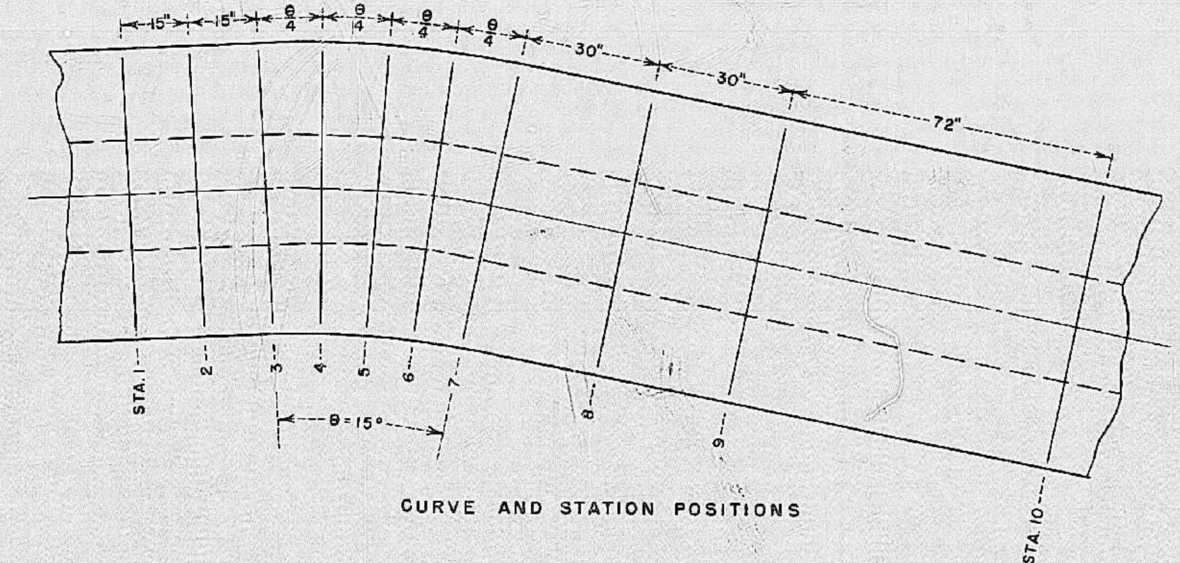


PLAN OF LABORATORY CANAL







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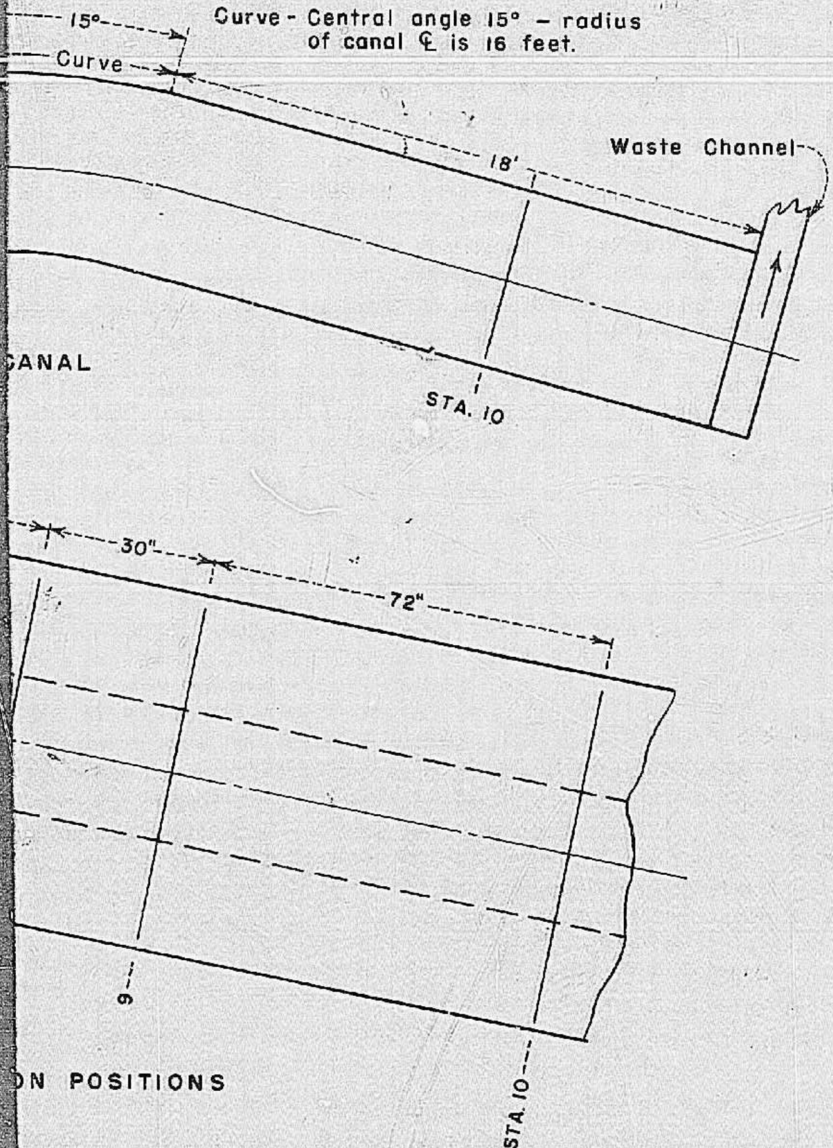
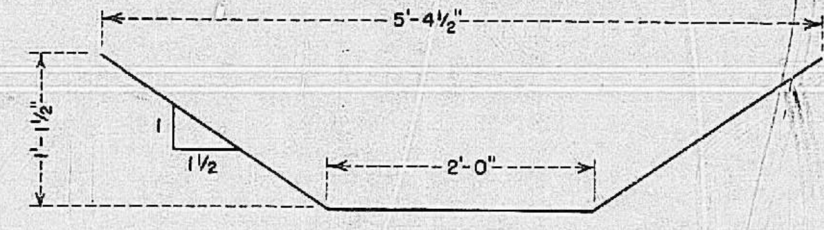
CURVE AND STATION POSITIONS

Laboratory canal looking upstr

DIAGRAM AND PHOTOGRAPH OF LABORATORY CANAL

668





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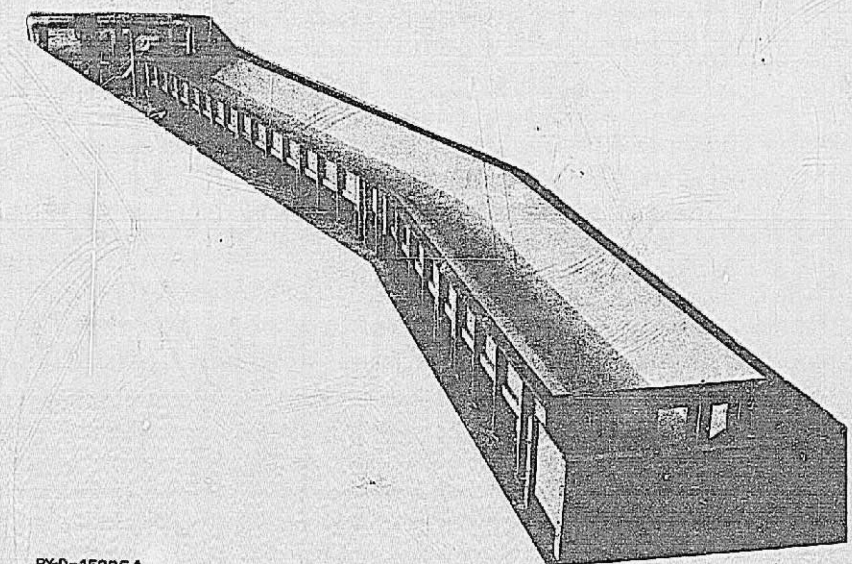

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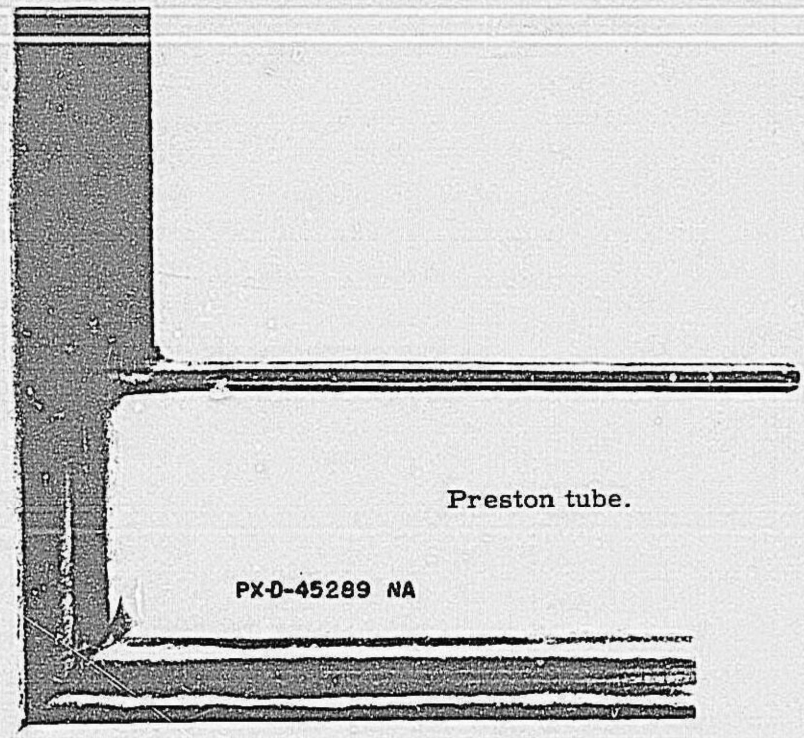
Laboratory canal looking upstream from the wasteway to the curve and inlet box.

CANAL

ON POSITIONS

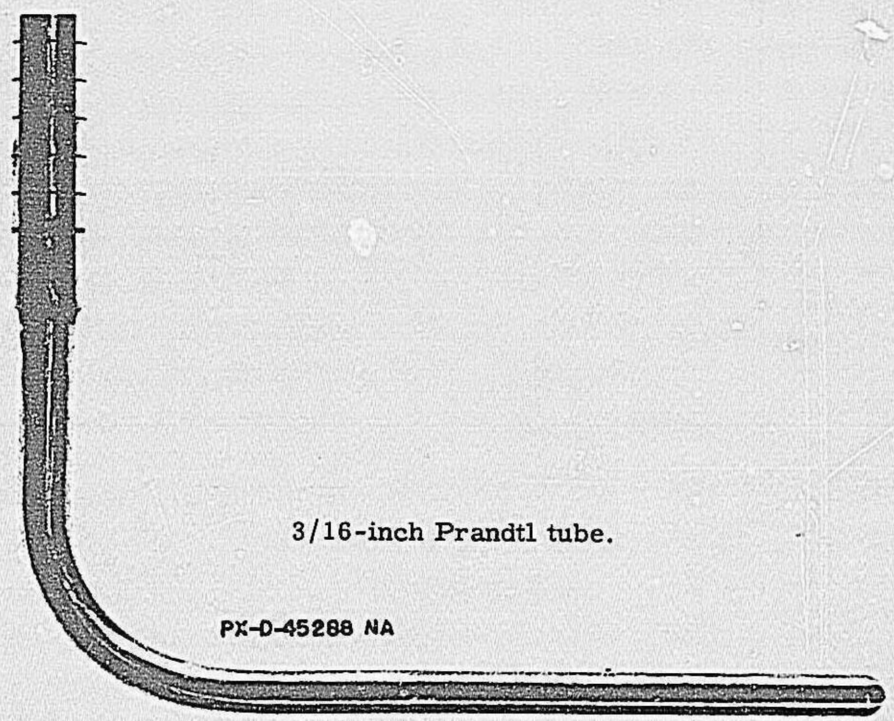
AND PHOTOGRAPH OF LABORATORY CANAL

Figure 2
Hyd-526



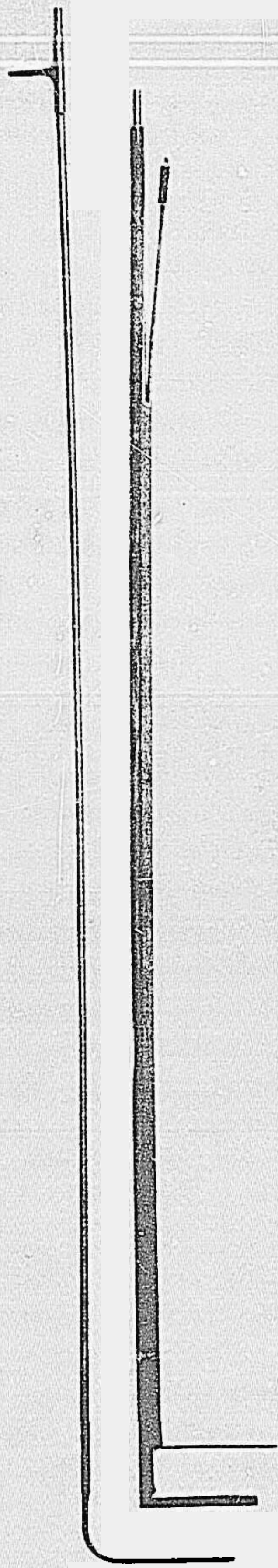
Preston tube.

PX-D-45289 NA



3/16-inch Prandtl tube.

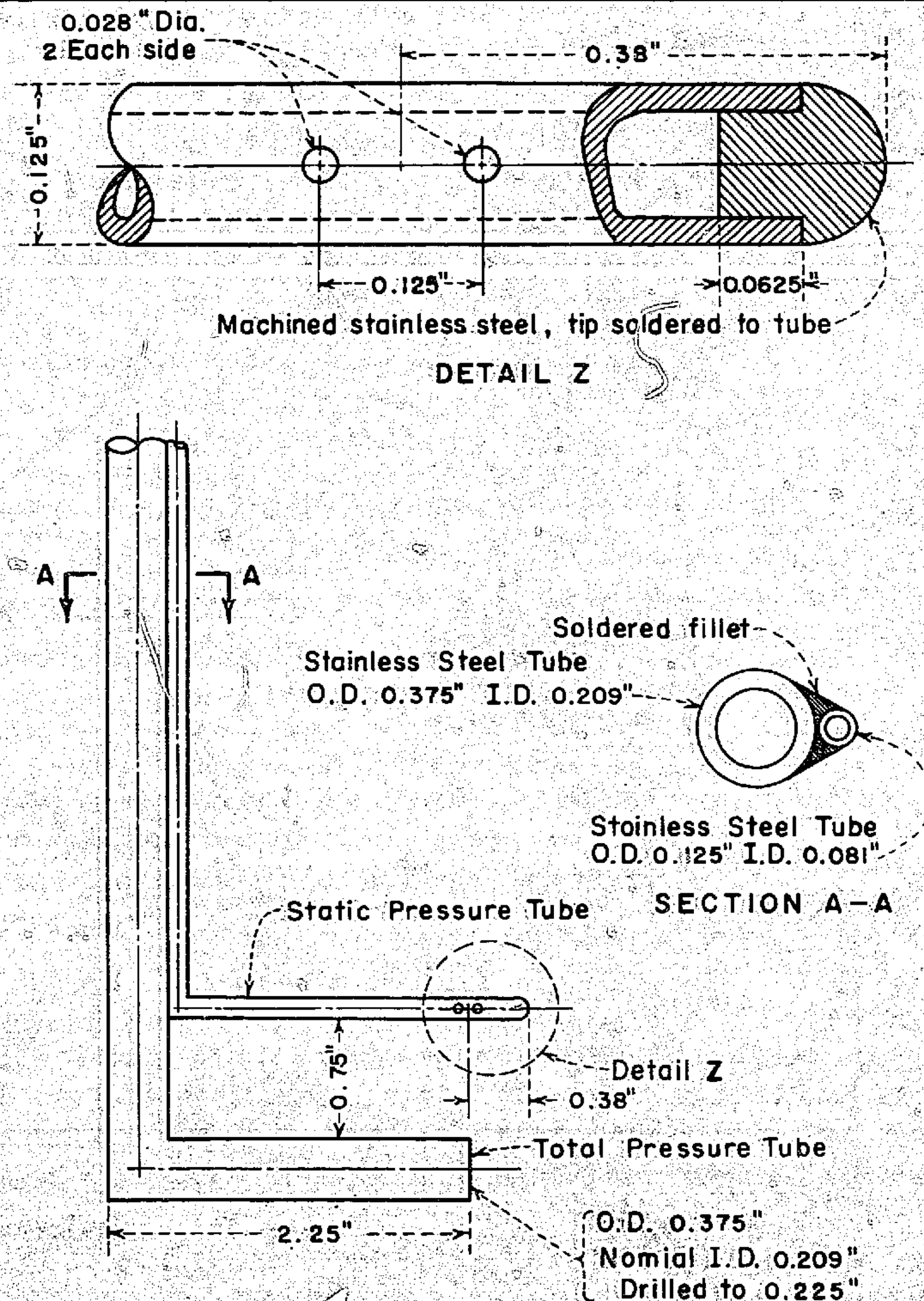
PX-D-45288 NA



Prandtl and Preston tubes.

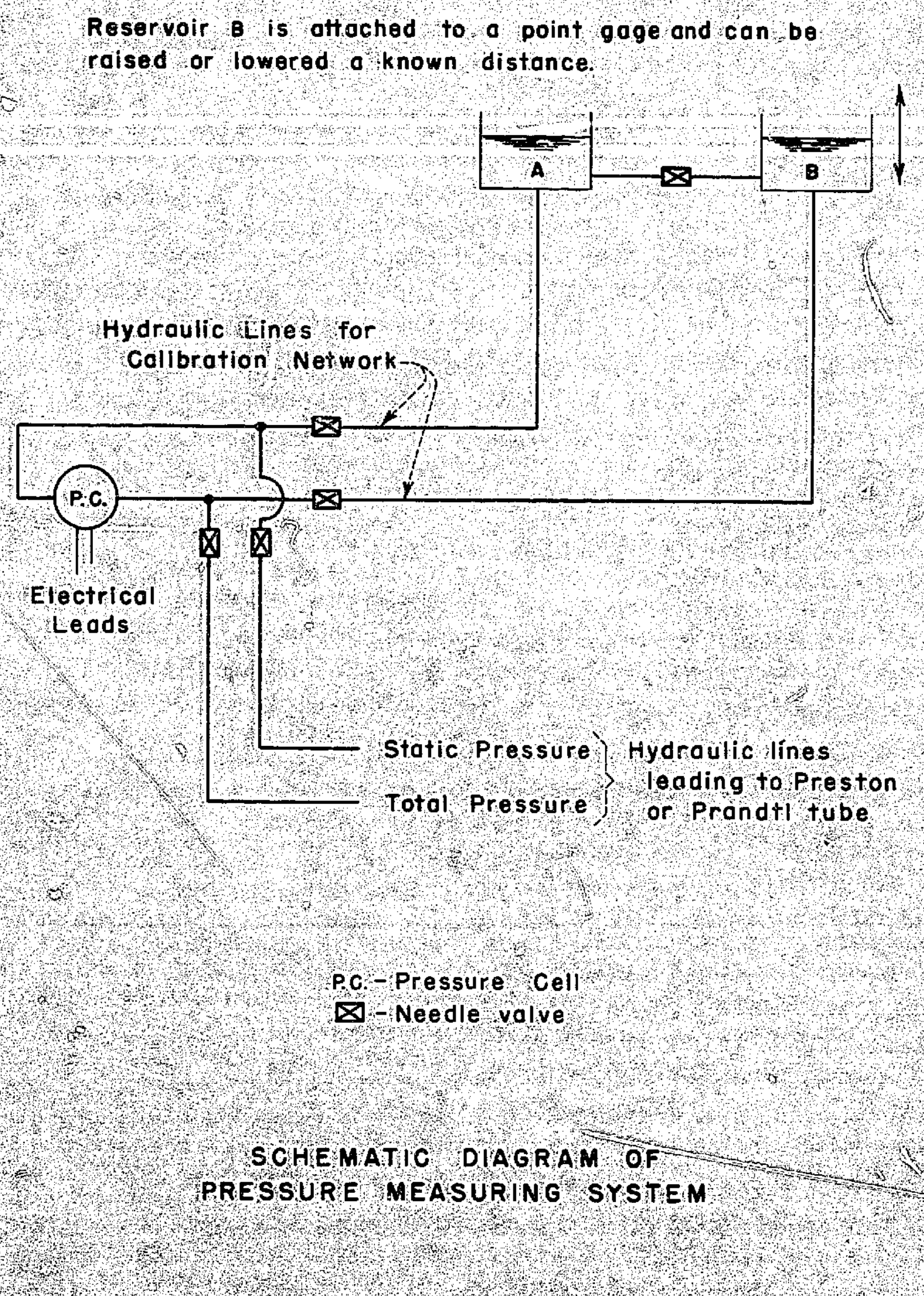
PX-D-45287 NA

Figure 3
Hyd-526



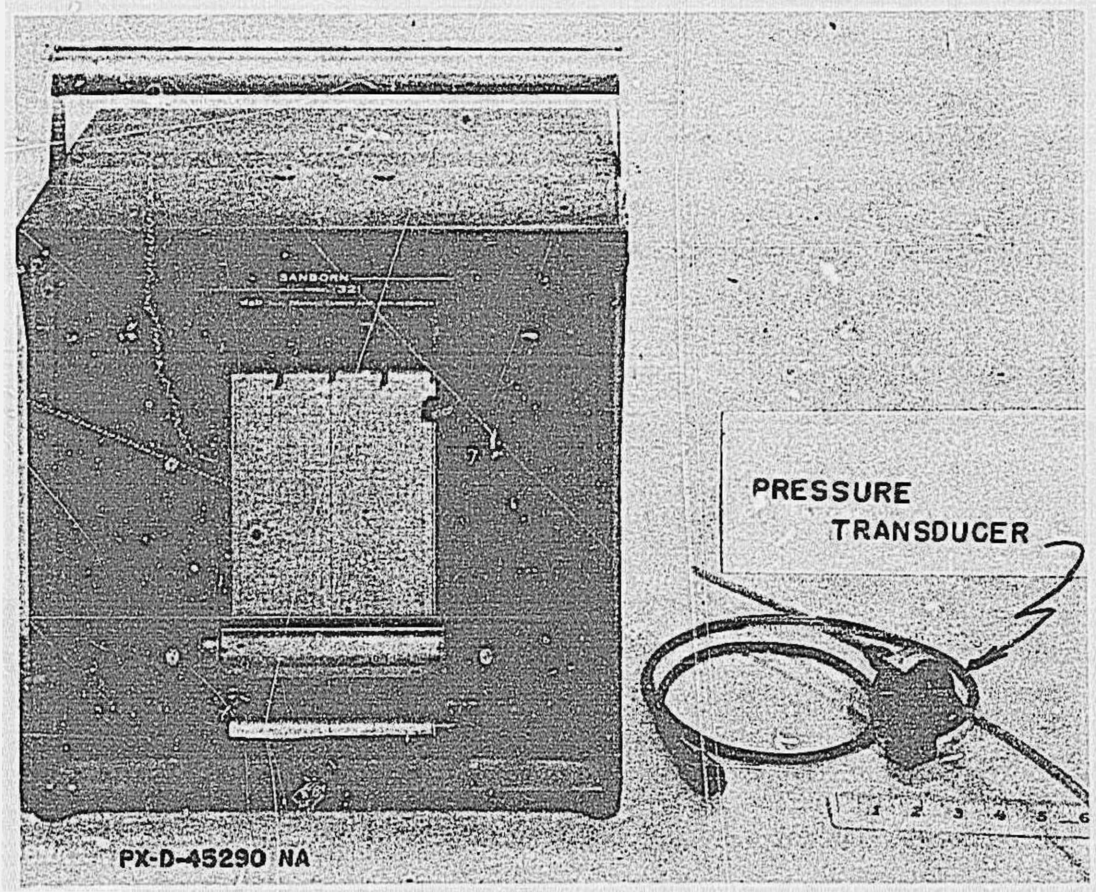
PRESTON TUBE
FOR MEASURING SHEAR DISTRIBUTION

668

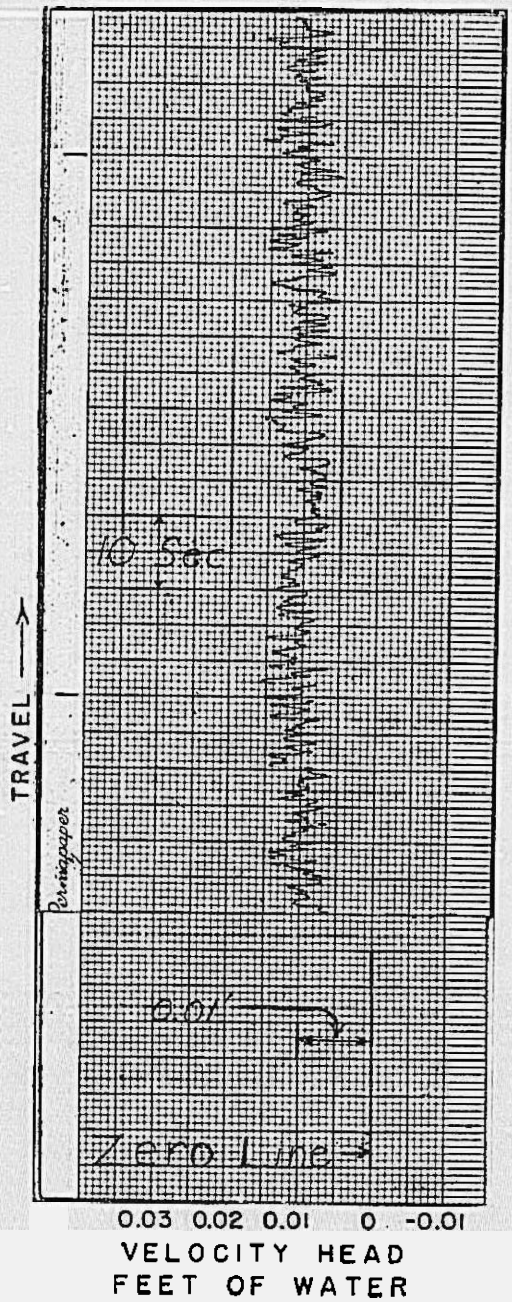


SCHEMATIC DIAGRAM OF
PRESSURE MEASURING SYSTEM

Figure 5
Hyd-526

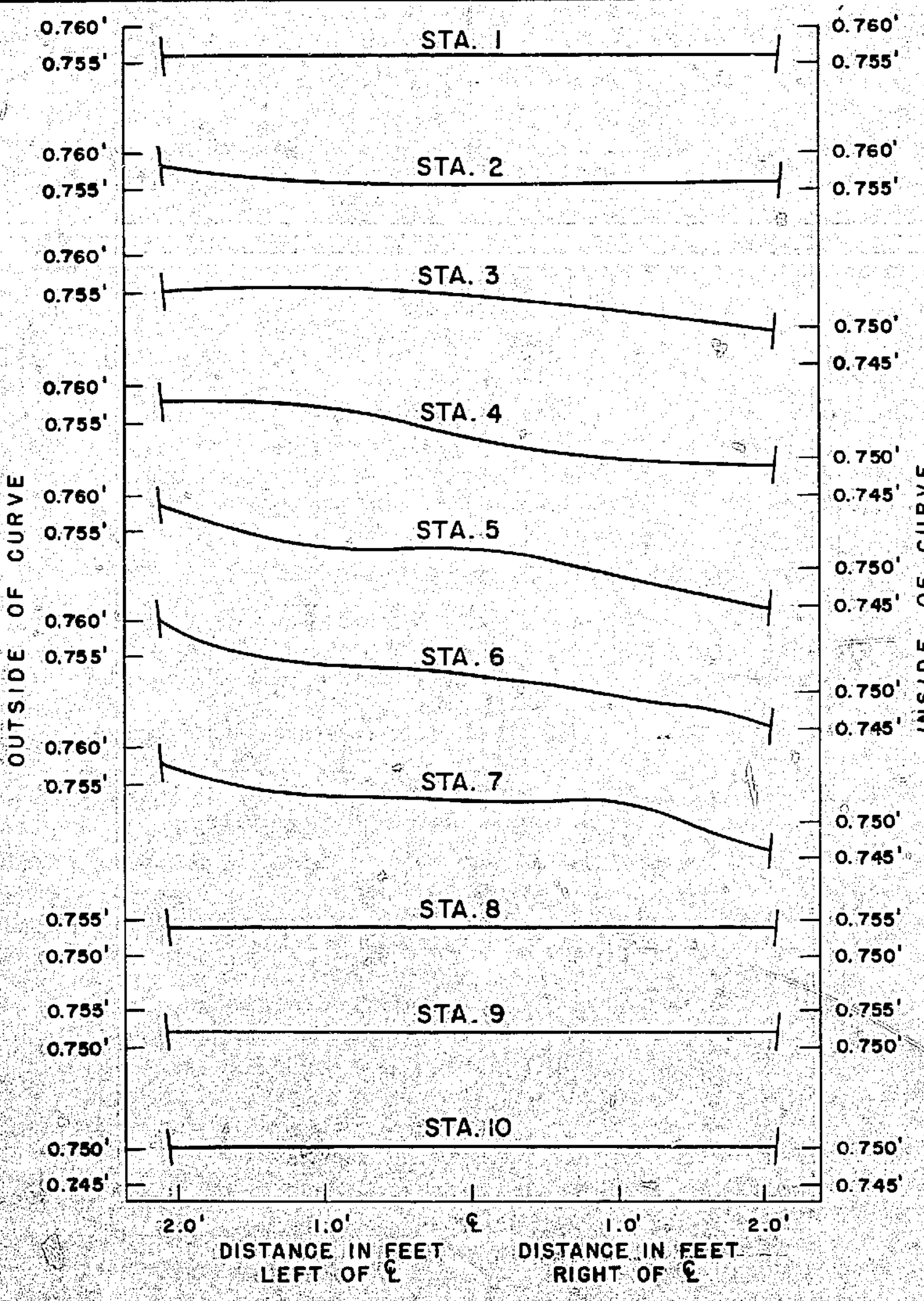


Direct-writing recorder and variable reluctance difference pressure transducer



RECORDER TRACE
OF
DIFFERENTIAL HEAD MEASUREMENT

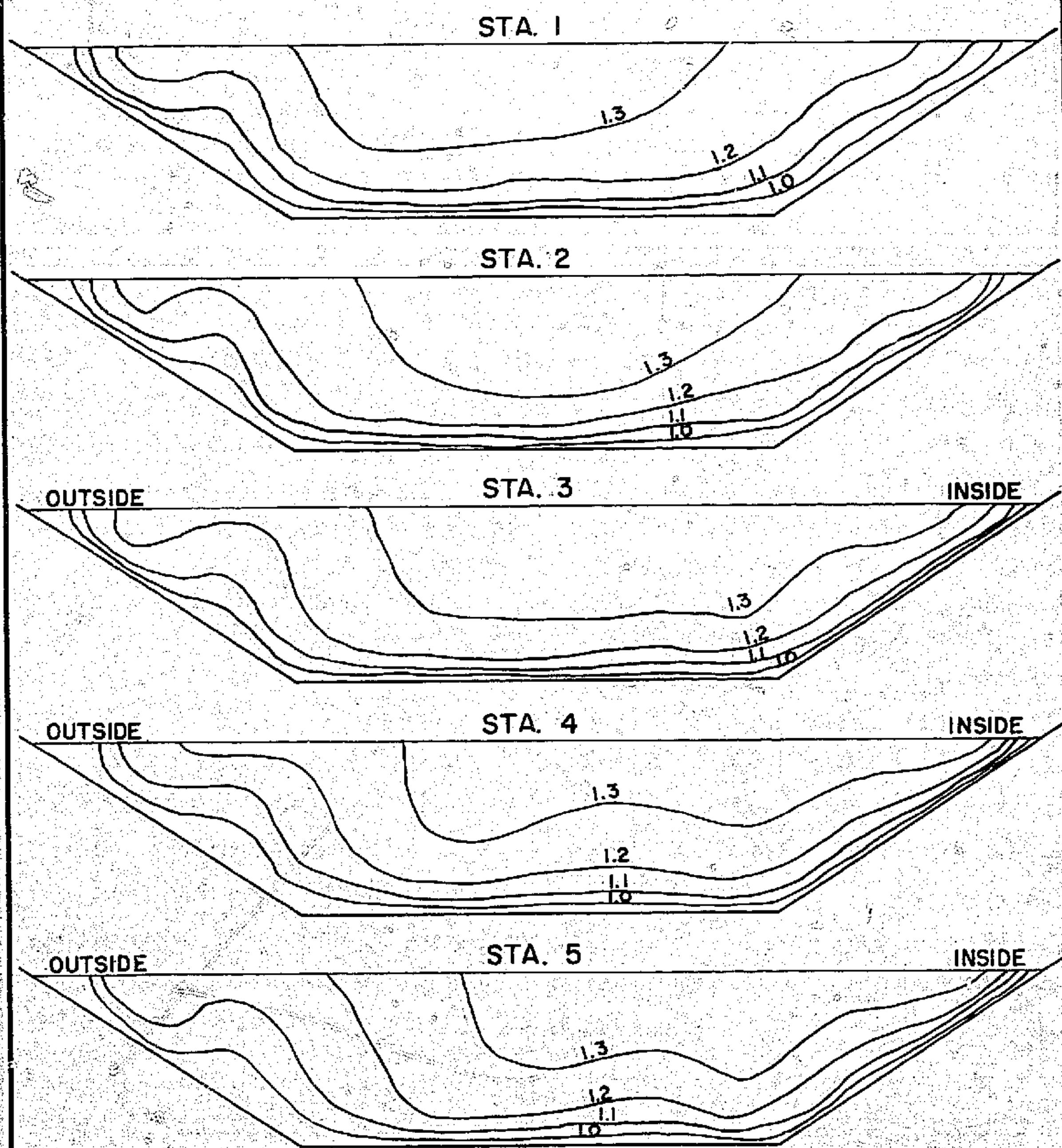
Figure 7
Hyd-526



WATER SURFACES - STATIONS 1 TO 10

Q = 2.85 CFS WATER DEPTH 0.75'

668

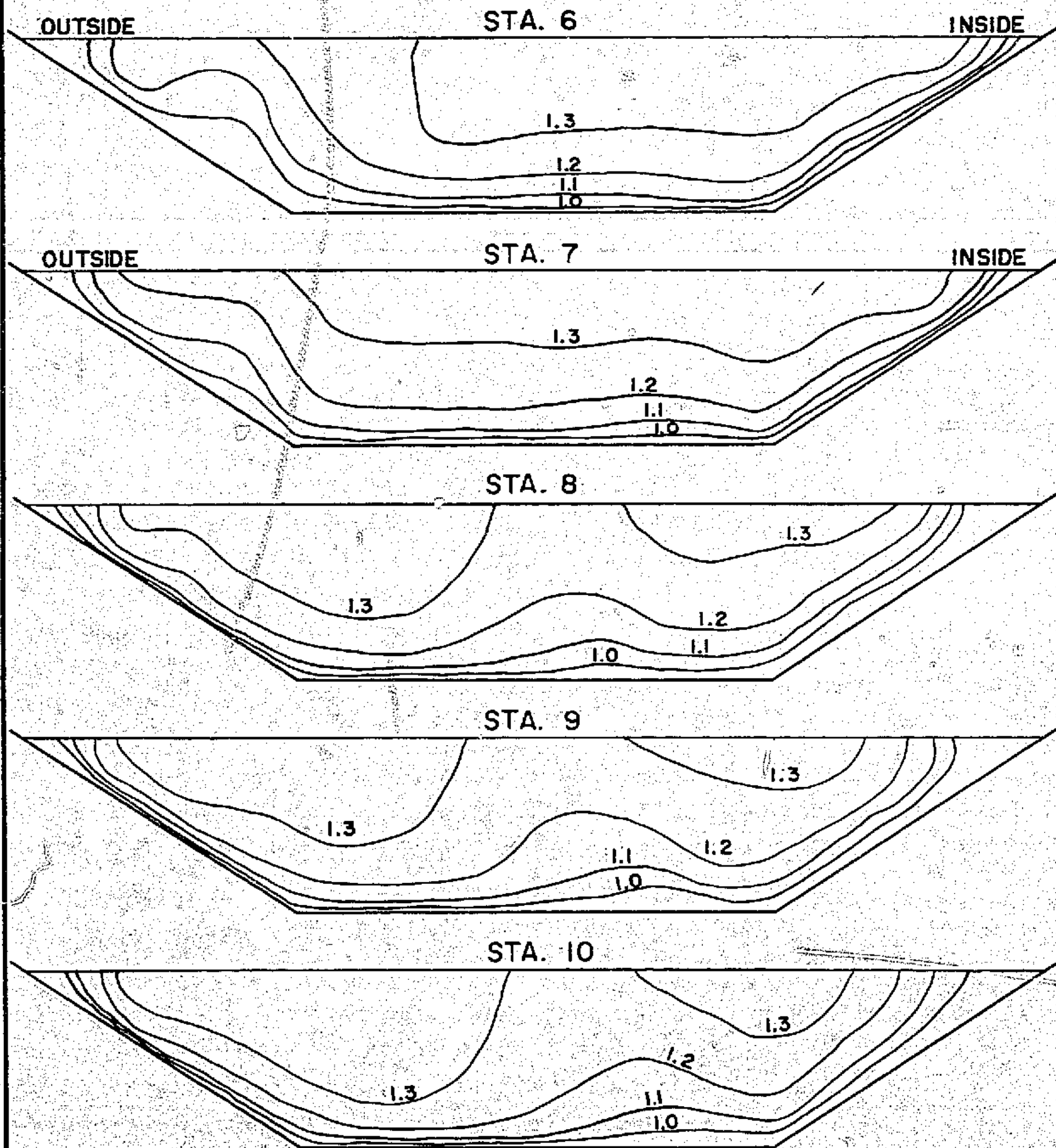


Velocity contours are labeled in feet per second.

VELOCITY DISTRIBUTION – STATIONS 1 TO 5

Q = 2.85 CFS WATER DEPTH 0.75'

Figure 9
Hyd-526

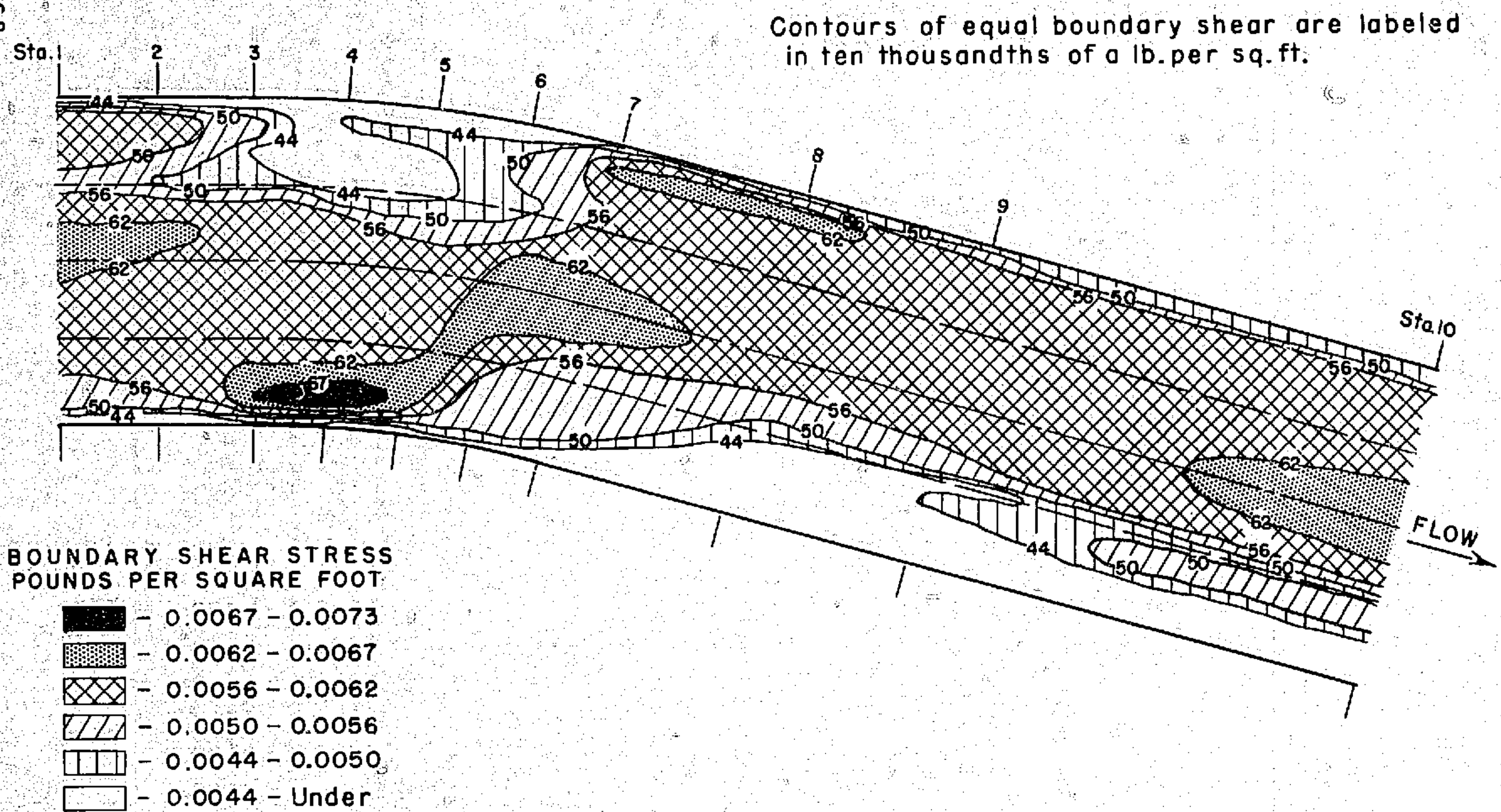


Velocity contours are labeled in feet per second.

VELOCITY DISTRIBUTION - STATIONS 6 TO 10

Q = 2.85 CFS WATER DEPTH 0.75'

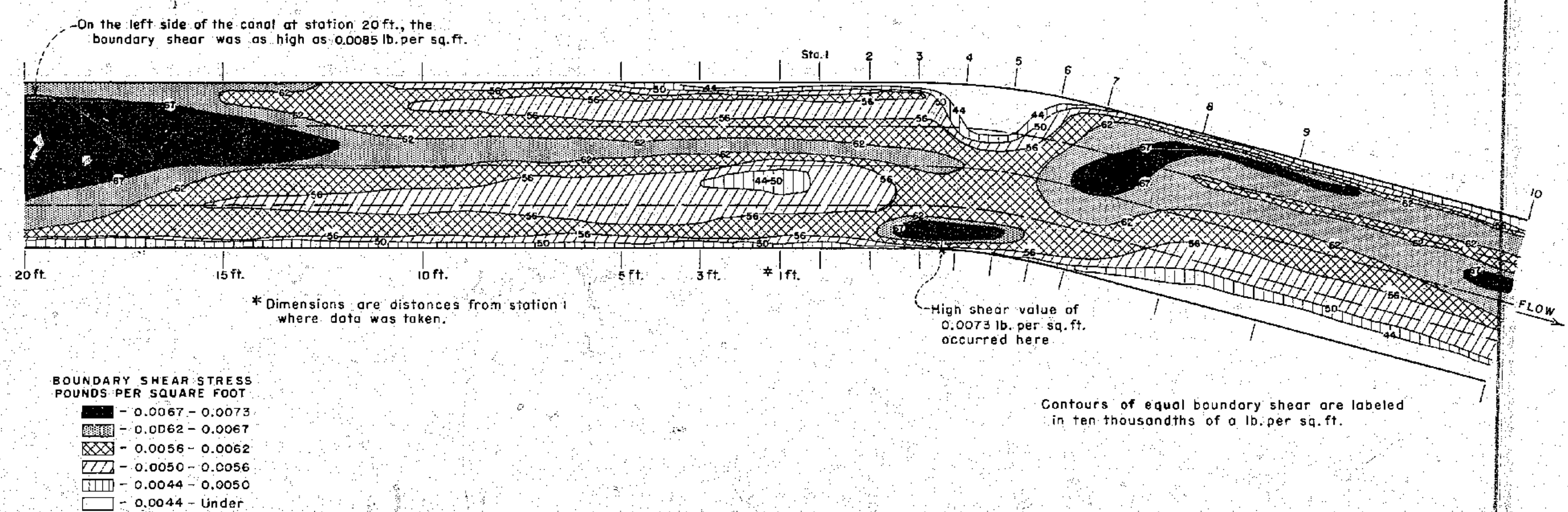
668



BOUNDARY SHEAR DISTRIBUTION

RUN NO. 1 Q = 2.85 CFS WATER DEPTH 0.75'

Figure 10
Hyd-526



BOUNDARY SHEAR DISTRIBUTION

RUN NO. 2 Q = 2.85 CFS WATER DEPTH 0.75'

668

ABSTRACT

Boundary shear distribution determined from hydraulic measurements in a rigid boundary trapezoidal laboratory canal showed that the highest boundary shear occurred on the inside bank at the upstream end and on the outside bank at the downstream end of the curve. Knowledge of how boundary shear varies around a curve and the location of its high and low areas will be helpful in understanding how to reshape a canal-bend cross section to provide maximum stability and in reducing maintenance costs on earth canals. The 50-ft-long by 6-ft-top-width test canal had a 16-ft-radius curve that turned a 15-deg angle with the channel centerline. Instrumentation included a Preston tube for boundary shear measurements, a Prandtl tube for velocity measurements, a point gage for water surface profiles, and a differential pressure transducer connected to a direct-writing electrical recorder for pressure measurements. Data were taken at 10 stations located upstream from, in, and downstream from the curve for 1 flow condition--discharge 2.85 cfs and depth 0.75 ft. Test results are given in graphs, drawings, and photographs showing boundary shear distribution throughout the tested reach, and velocity contours and transverse water surface profiles at 10 stations. In addition to the physical data, the study showed conclusively that boundary shear can be measured with a Preston tube and that shear distribution can be determined in a laboratory facility.

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Hyd-526
Zeigler, E. R.
PROGRESS REPORT I--BOUNDARY SHEAR DISTRIBUTION AROUND A CURVE IN A LABORATORY CANAL, United States Department of the Interior, Bureau of Reclamation, Hydraulics Branch Report No. Hyd-526, 1964, 11 figures.

DESCRIPTORS--*trapezoidal channels/ rigid boundaries/ canals/ steady flow/ open channel flow/ subcritical flow/ *boundary shear/ water surface profiles/ measuring instruments/ hydraulic laboratory/ velocity meter/ pressure measuring equipment/ recording systems/ velocity distribution

IDENTIFIERS--shear distribution/ differential pressure transducer/ point gage/ Preston tube/ Prandtl tube/ MIT/ canal curves

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HYDRAULIC CONVERSION TABLE

British to Metric Units

Multiply	By	To obtain
LENGTH		
Inches	25.4 (exactly)	Millimeters
Feet	30.48 (exactly)	Centimeters
Miles	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	0.092903 (exactly)	Square meters
Acres	0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic feet	0.0283168	Cubic meters
	28.3168	Liters
Gallons (U. S.)	3.78543	Liters
Cubic yards	0.7646	Cubic meters
Acre feet	1233.5	Cubic meters
MASS		
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Tons (2,000 pounds)	907.185	Kilograms
ACCELERATION		
Feet per second per second	0.3048	Meters per second per second
FORCE/UNIT AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Feet of water column (at 20° C)	2.246	Centimeters of mercury column
	0.03041	Kilograms per square centimeter
MASS/VOLUME (DENSITY)		
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Inches per hour	2.540 (exactly)	Centimeters per hour
Feet per year	0.3048 (exactly)	Meters per year
FLOW		
Cubic feet per second	0.028317	Cubic meters per second
	28.317	Liters per second
Cubic feet per minute	0.4719	Liters per second
Gallons per minute	0.06309	Liters per second
	3.7854	Liters per minute
POWER		
Horsepower (British)	745.700	Watts
(Defined 550 ft lb/sec)	1.014	Horsepower (Metric) (Defined 75 kg-m/sec)
SEEPAGE		
Cubic feet per square foot per day	304.8	Liters per square meter per day
VISCOSITY		
Dynamic Viscosity (Pound second per square foot)	4.8824	Kilogram second per square meter
Kinematic Viscosity (Square feet per second)	0.092903 (exactly)	Square meters per second
SURFACE TENSION		
Pounds per foot	1.4882	Kilograms per meter
GAS CONSTANT		
Feet per degree F	0.5486	Meters per degree Celsius*

*For all practical purposes, the Celsius and Centigrade scales are synonymous.

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